Seismic evaluation of low and mid-rise steel moment-resisting frames equipped with viscous dampers based on FEMA P-695 collapse capacity

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Abstract:

In this study, the seismic performance of steel special moment-resisting frames was analyzed under far-field records with and without viscous dampers using FEMA P-695. 4, 8, and 12-story frames were loaded, analyzed, and designed with and without viscous dampers based on ASCE 7-10 and AISC360. Furthermore, characteristics of viscous dampers are considered for the specific damping ratio of 15% (4,8-story), and 20% (12-story). The frames with and without dampers were modeled in OpenSees by lumped plasticity with Bilin Material. These frames were analyzed and calculated by Incremental Dynamic Analysis (IDA) under 44 far-field records with "Hunt & Fill" algorithm. The seismic performance of studied frames is presented as the collapse probability based on seismic fragility and collapse safety margin. The results demonstrate that the collapse capacity of 4, 8, and 12- story moment-resisting frames with viscous dampers have improved by 28%, 88%, and 74%, corresponding to the median collapse capacity. Moreover, the design of buildings with 75% of design base shear using viscous dampers has a significant effect on the optimal weight of building and construction costs, and improvement of seismic performance and technical criteria.

Keywords: steel moment-resisting frames, viscous damper, FEMA P-695, collapse capacity.

Introduction

In recent years, experimental and analytical studies have been conducted to use viscous dampers in structures. In 2015, Silwal et al. suggested a viscous dampers system to improve the seismic behavior of steel structures. It also demonstrated its efficiency by the experimental and analytical study on a 6-story steel special moment-resisting frame [1]. Lin et al. presented a method with nonlinear viscous dampers for modal response analysis of asymmetric-plan buildings in 2015 [2]. Studying the seismic performance of the special truss moment frame with the viscous damper in 2016, Kim et al. indicated that the proper performance is achieved. The effect of dampers has been significant in the final damage state [3]. Bannazadeh et al. in 2017 showed that the structures with linear damper possess proper seismic performance compared to those with nonlinear dampers. [4]. In 2019, Karavasilis and Kariniotakis studied the effect of using linear viscous dampers in peripheral moment-resisting frames for 5, 10, and 20-story buildings. The obtained results have shown the limits for interstory drifts, according to Eurocode-8. [5].

2. Characteristics of Models

In this study, 4, 8, and 12-story steel frames have been 3D modeled (Fig. 1), and then have been loaded, analyzed, and designed by ASCE 7-2010 [6] and AISC 360-2010 [7]. The P-delta effects and the strong column and weak beam principle have been considered in the design of frames. The plan of the studied buildings is regular and symmetric, and the dampers were located in the middle spans. Furthermore, the height of ground floor and other stories are 3.2 and 2.8 meters, respectively, while the span length of frames is 6 meters. Residential occupancy has been considered for buildings, and site specifications were extracted from USGS website introduced by ASCE 7–10 and were from Los Angeles, USA.

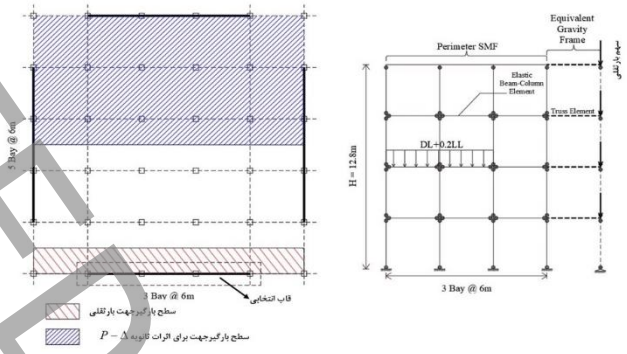
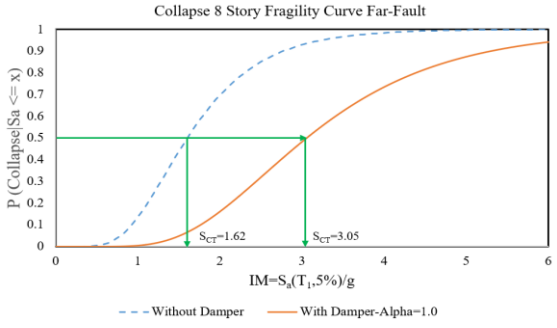


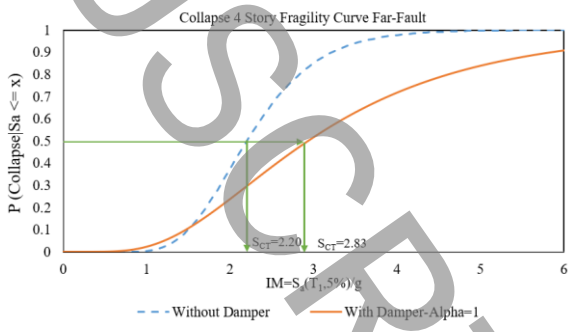
Figure 1. Plan of the studied buildings and the procedure for considering the Δ-p effect.

3. Fragility Curves

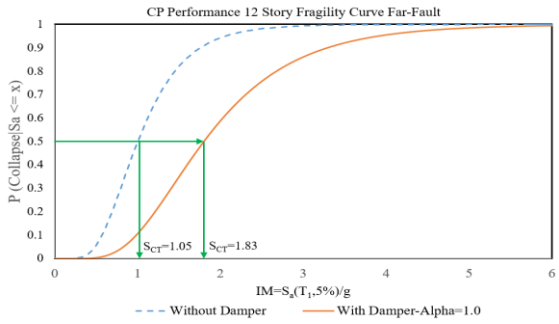
The use of dampers in a 4-story building has caused the median value of ($\hat{S}_{CT}$) collapse acceleration to increase from 2.20 to 2.83. In other words, the collapse capacity of the structure has been improved up %28 by applying the dampers (Fig. 1 (a)). The value of ($\hat{S}_{CT}$) has increased from 1.60 to 3.05 considering the mentioned effect for the 8-story building, which indicates an %88 improvement in the collapse capacity of the structure (Fig. 2 (b)). On the other hand, regarding the fragility curve of a 12-story building, the value of ($\hat{S}_{CT}$) has increased from 1.05 to 1.83 due to the use of dampers, implying a %74 increase in collapse capacity of the structure (Fig. 3 (c)).



8-story (b)



4-story (a)



12-story (c)

Figure 2. Comparison of the fragility curves for the buildings studied with and without the viscous damper.

4. Results

- The collapse capacity has increased mainly in the frames equipped with viscous dampers based on FEMA P695 procedure. The use of dampers in mid-rise buildings has been significant effects on the increase of collapse capacity.
- CP, IO, and GI seismic performances of studied frames in this research are acceptable under far-field records. Moreover, they have satisfied the criteria of design codes for loading and evaluation.
- The slope of the fragility curve has significantly decreased in frames with viscous dampers due to the ductility of structures during the collapse process.
- It has been found the median value of the collapse capacity of structures decreases as their height and the first-period increase, which is due to the altitude and subsequently, the P-Delta effect.

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